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Evaluation of accuracy of intra oral and extra oral complete arch scans on partially edentulous maxilla: An *in vitro* study

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Abstract
Digital technology and intraoral scanners have gained popularity in dental practice due to its advantages over conventional impression techniques, which includes reduced laboratory and chair time and implementation of a completely digital production workflow .the purpose of this article is to evaluate accuracy of intra oral and extra oral arch complete scan of partially edentulous maxillae. A standard maxillary typho model is modifed and scanned with medit T310 extra oral scanner and 3d printed. A digital vernier caliper was used to measure the distance between center of the ditch in incisal surface of right canine and incisal offset tip in left canine on the 3d printed reference model. One extra oral scanner (Rainbow Scanner structured light (Dentium Dental Laboratory 3D Scanner Rainbow) {group A} and Two intra oral scanners (structured light-3d-in-motion video technology MEDIT i 500 {Group-B}, structured light-optical triangulation and confocal microscopy UPCERA) {Group C} and were used to obtain the testing results. Each of these 3 scanners performed 10 scans of the reference model. Mean comparison and P values are 0.174mm & 0.006, 0.161mm & 0.026 and 0.223 & 0.023 mm respectively. This shows that Group A (rainbow) scanner has highest precision among the three types of scanners. The group B (medit i500) scanner has highest trueness among the three types of scanners. The difference of all the three scanners with reference data is significant but among themselves its insignificant.

Keywords: Arch scans, accuracy, extra oral scanners, intra oral scanners, 3D Printing

Introduction
Digital technology and intraoral scanners (IOSs) have gained popularity in dental practice due to its advantages over conventional impression techniques, which includes reduced laboratory and chair time and implementation of a completely digital production workflow [1-6]. Definition of CAD/CAM: CAD is the abbreviation for "computer-aided design" and CAM stands for "computer-aided manufacturing". All CAD/CAM systems consist of three components:
1. A digitalization tool/scanner which transfers the geometry into digital data that can be processed by the computer.
2. Software for processing the data.
3. A production technology /milling unit that transforms the data set into the desired product [2].

There exist two techniques for creating digital impressions, Intra oral scanners and Extra oral scanners . Intraoral scanning allows the clinician to directly acquire the data from the prepared abutment without the need to make conventional impressions and pour the casts, and it results in a 3D virtual model. Extraoral laboratory scanner, where a conventional impression is needed .Then scanning of the dental impression or gypsum casts to create a 3D model and the restoration is then designed on computer with special design software and then 3D printed [2, 3, 5, 9, 11]. The accuracy of a dental impression is determined by two factors: "Trueness" and "Precision". These variables are independent and do not reflect the same thing. Trueness is defined as the comparison between a reference dataset and a test dataset. Trueness shows how similar is a measurement to the value of the measured quantity.

A high trueness delivers a result that is close or equal to the real value of the measured object. Precision is defined as a comparison between various datasets obtained from the same object using the same scanner. Precision shows how much similar are repeated measurements, in other words the reproducibility of the impression. The higher the precision, the more predictable is the measurement [3-5].
An accurate impression is essential in achieving a well-fitting and durable restoration. A restoration with a marginal discrepancy of 50 to 100 micrometers has been considered acceptable for CAD-CAM [5, 13, 37].
Various scanners have been introduced based on different principles. As limited literature is available comparing the scanners based on these diverse principles, this study was aimed to evaluate the differences in the accuracy of the 3D image duplicated with different commercially available digital scanners with different principle.

Materials and Methods

Materials used in the study: The following materials were used in the study:

- Standard Typho tooth in typho base
- Standard Tooth preparation diamond burs
- BR 40 diamond bur
- Grey colored Any cubic 3D printer resin material

Equipments used in the study

- Digital Vernier Caliper (Insize Digital Calipers; Bombay tools; India).
- Medit T310 3D scanner.
- Rainbow Scanner (Dentium Dental Laboratory 3D Scanner Rainbow, South Korea).
- Upcera scanner.
- Medit i500 (MEDIT corp; South Korea).
- EXOCAD software (exocad Dental CAD; Germany).

Methodology

The methodology of the study includes the following stages: I. Preparation of reference model II. Obtaining reference data III. Obtaining study data IV. Evaluation of study data in software V. Results VI. Statistical analysis.

Preparation of reference model: A standard modified typodont was used for the study. Both central and lateral incisor along with left second premolar, second and third molar were removed. For left canine and first premolar three fourth crown preparation is done. All ceramic crown tooth preparation is done for all the remaining teeth in right arch expect third molar the standard preparation guide lines are followed for all tooth preparations. With the help of BR 40 bur a small ditch is made on incisal surface of right canine. The prepared typho model [Figure 1] is scanned with medit T310 scanner [Figure 2] and 3D model of the typho is printed in ultimaker 2 + 3d printed model whos precision is said to be 12.5/12.5/5 micro meters in xyz position with grey colored Any cubic 3D printer resin material [Figure 3].

Obtaining reference data: A digital vernier caliper was used to measure the distance between center of the ditch in incisal surface of right canine and incisal offset tip in left canine on the 3d printed reference model. Thus the reference data was obtained [Figure 4].

Obtaining study data: One extra oral scanner (structured light -Rainbow Scanner (Dentium Dental Laboratory 3D Scanner Rainbow [Figure 5]) and Two intra oral scanners (structured light-3d-in-motion video technology MEDIT I 500 [Figure 6], structured light-optical triangulation and confocal microscopy UPCERA [Figure 7]) and were used to obtain the testing results. Each of these 3 scanners performed 10 scans of the reference model. The scans were made using the workflow parameters regularly followed in daily practice, with no modifications.

Evaluation of study data in software: The ExoCad software was used (which was open architecture CAD software), forthe evaluation of the digital images obtained from the extraoral & intraoral scanners and for designing various dental prostheses. The software allows evaluation of the digital images and is accurate till up to three decimals while making measurements. The images obtained from the scanners were processed on the computer and further evaluation was done using the ExoCad software. The datasets obtained were in Standard Tessellation Language (STL) file format and were exported to the evaluation software (ExoCad). Measurements for these datasets were made by measuring the distance from center of the ditch in incisal surface of right canine and incisal offset tip in left canine [Figure 8, 9,10].

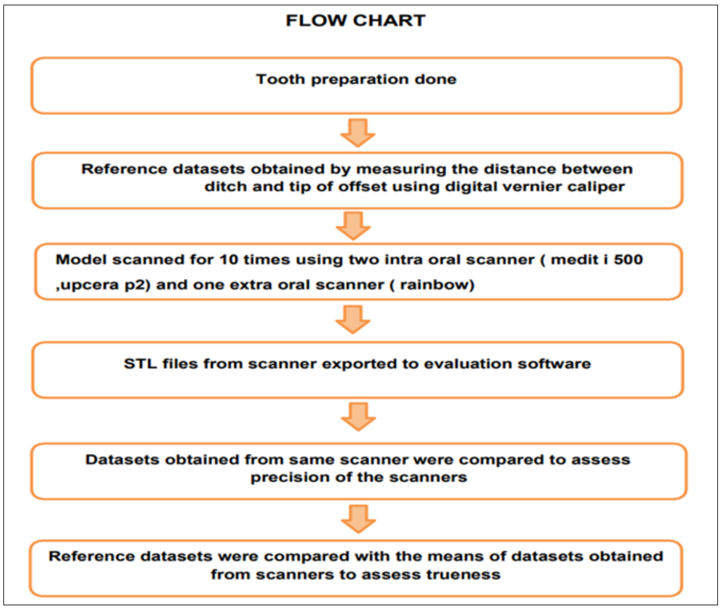


Fig 1: Typho model	**Fig 2:** Typho model scanned using Medit T310 exra oral scanner

Fig 3: Reference model	**Fig 4:** Measuring distance with digital vernier caliper on reference model

Fig 5: Reference model scanned using Rainbow scanner [Group A]	**Fig 6:** Reference model scanned using Medit i500 scanner [Group B]	**Fig 7:** Reference model scanned using UPCERA scanner [Group C]

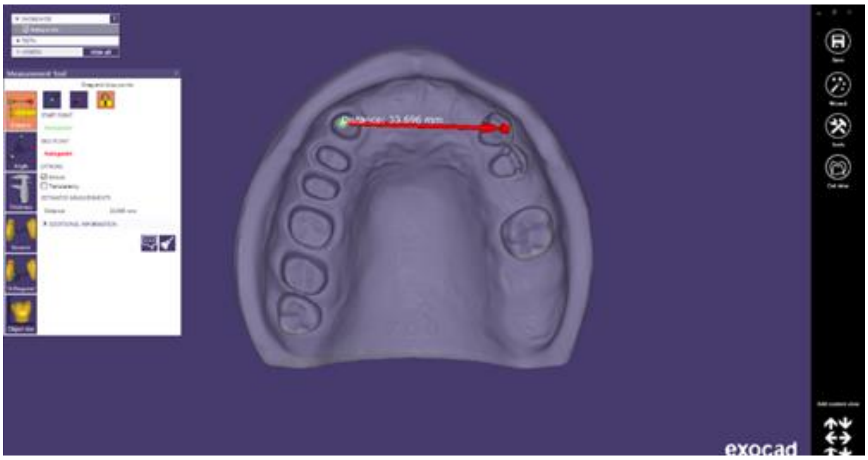


Fig 8: Showing study model values of Group A scanners In Exocad software

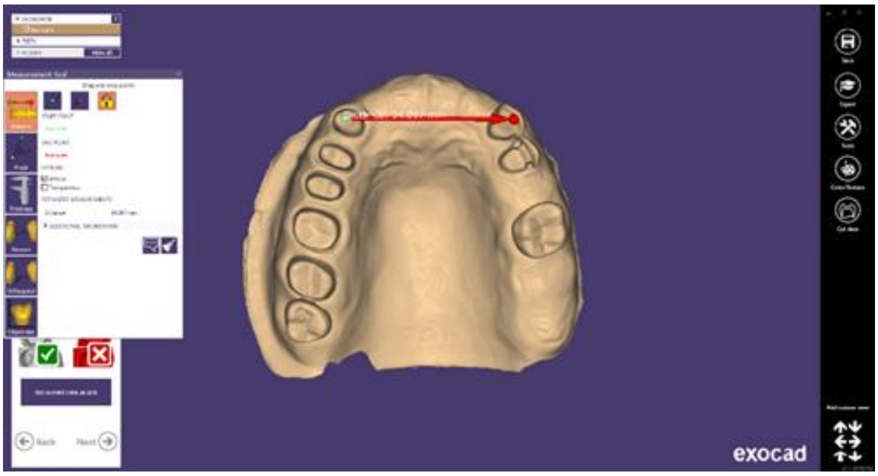


Fig 9: Showing study model values of Group B scanners in Exocad software

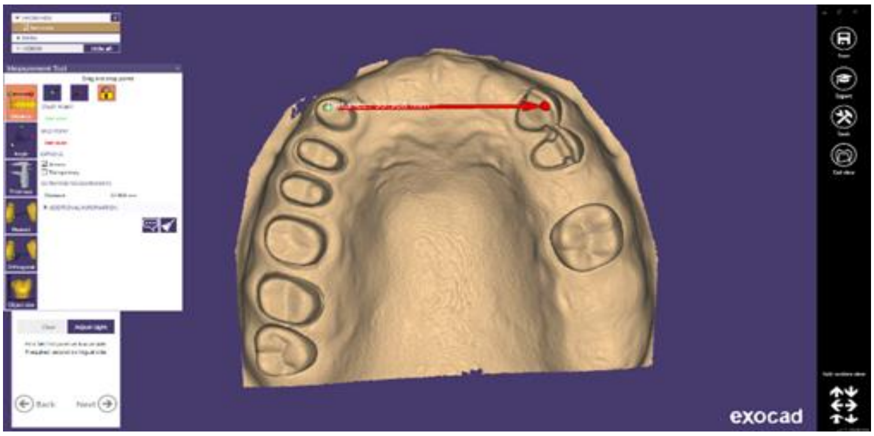


Fig 10: Showing study model values of Group C scanners in Exocad software

Observation and results

The null hypothesis of the present study was that no differences would be found between the various scanners regarding accuracy. The readings obtained from the scanners were tabulated. The datasets from the same model were compared with each other, to assess the precision of the scanners by evaluating the standard deviation. To assess the trueness, the reference data set was compared to the means data sets obtained from the scanners. The results obtained were subjected to statistical analysis using repeated measure ANOVA .the mean and standard deviation of each group was assessed using descriptive statistics.

Statistical Analysis

Table 1: Reference length dataset obtained from digital vernier caliper

Reference data	33.520

Table 2: Datasets obtained from different scanners

S. No.	Group A Rainbow	Group B Medit i500	Group C Upcera
1	33.517	33.489	34.092
2	33.673	33.851	33.770
3	33.351	33.696	33.903
4	33.660	33.534	33.803
5	33.777	33.766	33.379
6	33.968	33.566	33.354
7	33.864	33.964	33.640
8	33.617	34.013	33.973
9	33.714	33.531	34.103
10	33.807	33.403	33.421

Table 3: Mean comparison of accuracy between Reference data and mean of Group A (Rainbow)

Group	Mean	Std. Deviation	Mean difference	T	P-Value
Reference data	33.52000	0.000000	-0.1748	-3.131	0.006*
Group A (Ranbow)	33.69480	0.176550			

Independent t-test; $p \leq 0.05$ considered statistically significant

Table 4: Mean comparison of accuracy between Reference data and mean of Group B (Medit i500)

Group	Mean	Std. Deviation	Mean difference	T	P-Value
Reference data	33.52000	0.000000	-0.16130	-2.425	0.026*
Group B (Ranbow)	33.68130	0.210328			

Independent t-test; $p \leq 0.05$ considered statistically significant

Table 5: Mean comparison of accuracy between reference data and Group C (Upcera)

Group	Mean	Std. Deviation	Mean difference	T	P-Value
Reference data	33.52000	0.000000	-0.22380	-2.481	0.023*
Group B (Ranbow)	33.74380	0.285254			

Independent t-test, $p \leq 0.05$ considered statistically significant

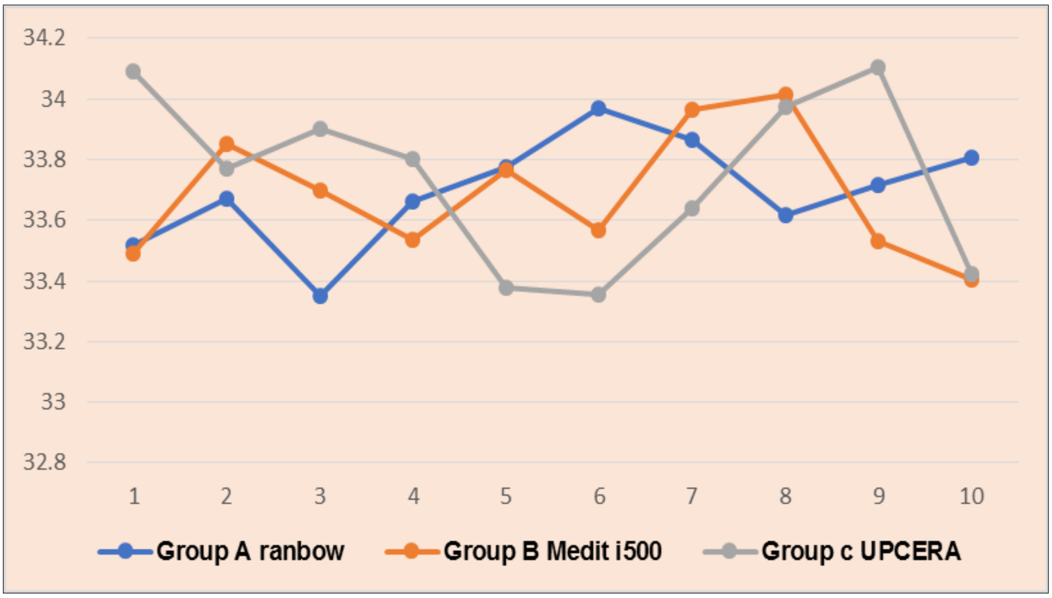
The difference of all the three scanners with reference data is significant but among themselves its insignificant.

The standard deviation of the 10 scans obtained from each scanner is measured to assess the precision. The rainbow scanner showed least standard deviation amongst all the scanners and the mean value of Medit i500 is closest to reference data set.

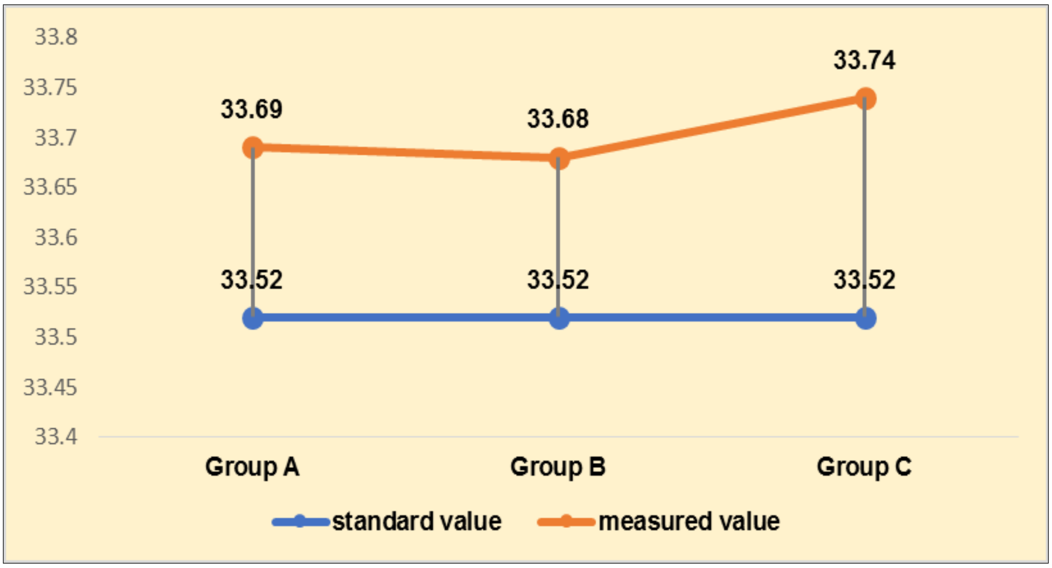
Table 6: Mean comparison of accuracy between groups

Groups	N	Mean	SD	F-Value	P-Value
Group A (Rainbow)	10	33.6948000	0.17655078	0.207	0.814
Group B (Medit i500)	10	33.6813000	0.21032887		
Group C (Upcera)	10	33.7438000	0.28525497		

ANOVA test; $p \leq 0.05$ considered statistically significant



Graph 1: Comparison of deviations between the groups for precision of scanners



Graph 2: Mean comparison of mean value of each group with standard value for trueness

Inference

1. The group A (Rainbow) scanner has highest precision among the three types of scanners.
2. The group B (Medit i500) scanner has highest trueness among the three types of scanners.
3. When compared group C (Upcera, structured light-optical triangulation & confocal microscopy) has least accuracy.
4. The difference of all the three scanners with reference data is significant but among themselves its insignificant.

Discussion

Scanners are data collection tools that measure three dimensional jaw and tooth structures and transform them into digital data sets. Basically there are two different scanning possibilities, optical scanners and mechanical scanners. The triangulation process gathering of three-dimensional structures serves as the foundation for an optical scanner. In this instance, the receptor unit and the light source (such as a laser) are positioned at a specific angle to one another. By using this angle, the image on the receptor unit may be used by the computer to construct a three dimensional data set. A laser beam or white light projections can be used as the light source. With a ruby ball, the master cast is mechanically read line by line in a mechanical scanner, and the three-dimensional structure is measured [2]. Optical scanners-laser and structured light are not impacted by the object's density during the scanning process, and they typically operate at a faster pace than contact scanners because they don't require physical touch. The shine, brightness, or other optical characteristics of the object being scanned, however, have no effect on contact scanners [15]. Structured light is commonly used as the most reliable method of depth estimation in the field of non-contact 3D sensing. "Structured light" is the projection of simple or encoded light patterns onto an illuminated scene. Its main purpose is to aid in the extraction of features from camera-captured pictures and expedite the pairing process. As in conventional stereoscopic systems, triangulation is utilized to quantify 3D information using structured light once comparable points are located [25].

In optical scanner there are two types intra oral and extra oral. The present study compared accuracy of two intra oral scanner and one extra oral scanner. Dentium Rainbow scanner [GROUP A] which works on structured white light principle with a camera resolution of 2 MP. Medit i500 scanner [GROUP B] which works on 3D in motion video technology / 3D full color streaming capture. Upcera intra oral scanner [GROUP C] which works on structured light-optical triangulation and confocal microscopy. In this study the study model / reference model was prepared on typho model and scanned with medit t310 3D extra oral scanner and 3D printed with FDM 3D printing technique. Sason, *et al*. [3] compared the accuracy of an intraoral and an extraoral scanner by measuring the distance between the dimples placed on the tooth. In this study, a similar methodology was adopted for measuring the distance between the dimple and offset tip for the accuracy of two intra oral and one extra oral scanner. The study model was scanned ten times using each dental scanner and ten data sets obtained per scanner in STL file format which were transferred to Exocad software for evaluation. A digital vernier caliper was used to obtain reference data set. The reference dataset length is 33.520 mm and mean values of Group A, Group B and Group C are 33.694 mm, 33.681mm and 33.743 mm respectively. Mean comparison and P values are 0.174mm & 0.006, 0.161 mm & 0.026 and 0.223 & 0.023 mm respectively. This shows that group A (Rainbow) scanner has highest precision among the three types of scanners. The group B (Medit i500) scanner has highest trueness among the three types of scanners. The accuracy of scanners with reference dataset was statistically significant i.e. P-Value $\leq$ 0.05 but when compare with in themselves they are insignificant. It is challenging to explain the source of the deviations because the scanners use different scan technologies and algorithms.

There have been many previous studies evaluating the accuracy of 3D scanners. [7-23, 24, 28, 36]. Baghani MT, *et al*. [5] conducted a study in comparison to two of the intraoral devices (Sirona and Carestream), the desktop scanner (Deluxe desktop scanner; Open Technologies) shown reduced variance in tooth scanning which suggest better accuracy than two intra oral scanners. This contradicts a research by Bohner, *et al*. [26] which found that intraoral scanners were more accurate than desktop scanners when comparing intraoral and extraoral scanners using an industrial X-ray computed tomography scanner as a reference.

Flügge, *et al*. [11] in there study stated that extra oral scanner show more accuracy than intra oral. According to Mehl, *et al*. [27] and Sason, *et al*. [3] an intraoral scanner was more accurate than an extraoral scanner. When searching for prepared teeth, extraoral scanning yielded higher accuracy than intraoral scanning, according to Luthardt, *et al*. Both intraoral and extraoral scanner types' accuracy falls within the limit of clinical acceptability, according to Shah, *et al*. review article. However, in a partial arch scenario, the intraoral scanners appear to be more accurate than the extraoral scanners [23]. Lee *et al*. [20] stated that for a quadrant scanning, both intraoral and extraoral scanners are recommended, but extraoral scanners are recommended for a full-arch scanning.

Ender, *et al*. [13] analyzed 15 virtual models acquired by each intraoral scanner in the clinical environment, and Flügge, *et al*. [11] analyzed 10 digital models acquired in the clinical environment, the findings of which suggest that intraoral conditions (saliva, limited intervals) contribute to scan inaccuracy[11,13] . However, the present study was not evaluated in the clinical environment but was evaluated using a reference model in an *in vitro* environment it did not consider errors that may occur in the clinical environment. Therefore, further research is needed in the actual clinical environment.

The primary distinctions between these studies are to methodology, since distinct preparations, including as inlay and on lay preparations, complete-arch scans, and fixed dental prosthesis preparations, were scanned and assessed. Consequently, intraoral scanners might be appropriate for certain treatments; nonetheless, there is ongoing discussion regarding their efficacy in comparison to extraoral scanners.

The null hypothesis of the present study was that no differences would be found between the various scanners regarding trueness and precision. The null hypothesis was rejected i.e. significant differences were found among the digital impression systems regarding trueness and precision.

Limitations

Limitation of this study was lack of standardization of the methodology used for testing the scanners. ADA as well as the literature lacks a standardized methodology to test the dental scanners. Further studies are required to describe the direction specific accuracy of scanner

Conclusion

From this study it is concluded that

1. When compared Group A (extra oral scanners Rainbow with structured light) scanner has highest precision among the three types of scanners.
2. When compared group B (Medit I 500, intra oral digital scan of structured light3d-in-motion video technology) scanner has highest trueness among the three types of scanners.
3. When compared group C (Upcera, structured light-optical triangulation & confocal microscopy) has least accuracy.
4. The difference of all the three scanners with reference data is significant but among themselves its insignificant.

Conflict of Interest
Not available

Financial Support
Not available

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